Dry Matter Production of Orchardgrass and Perennial Ryegrass at Five Irrigation Levels

Kevin B. Jensen,* Kay H. Asay, and Blair L. Waldron

ABSTRACT

Within the Great Basin, availability of irrigation water throughout the growing season is the limiting factor in the development of improved pastures. The choice of species and their water requirements are critical factors for providing a stable source of forage throughout the grazing season. A line-source irrigation system was used from 1995 to 1998 to evaluate dry matter (DM) production and seasonal forage distribution of nine orchardgrass (*Dactylis glomerata* L.) and perennial ryegrass (*Lolium perenne* L.) hybrid cultivars along with check cultivars of meadow brome (*Bromus riparius* Rehm.) and smooth brome (*B. inermis* Leyss.), tall fescue (*Festuca arundinacea* Schreb.), and quackgrass [*Elytrigia repens* (L.) Nevski] × bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Love] hybrids (RS) under five irrigation levels ranging from 41 to 91 cm per year. Mean DM production rankings across water levels combined over years were tall fescue > orchardgrass > meadow brome > RS-hybrid > smooth brome > perennial ryegrass-hybrids. The DM production response across water levels was largely linear with a minor but significant quadratic component at lower water rates. Tall fescue was most responsive (i.e., produced more DM production) to increased irrigation rates. At lower water levels, meadow brome outyielded orchardgrass. However, when water was not limited, orchardgrass outyielded meadow brome. The RS hybrid and smooth brome had relatively low DM production at both low and high water levels. All species produced significantly ($P < 0.01$) more DM than perennial ryegrass at lower water levels. Under limited irrigation, tall fescue and meadow brome will produce more DM.

As early as the mid 1950s, Bateman and Keller (1956) recognized that pastures played an important role in the agricultural economy within the Intermountain West. They concluded that as long as nearby valley bottoms or other public land not well suited for cultivation were available, pressure for more productive pastures remained secondary to that for cash crops. Grazing on public lands in the West is becoming more restricted by environmental pressures and a limited water supply, particularly in the later portions of the growing season. Interest in maximizing the potential of private irrigated grazing lands has escalated. Productivity of these lands can be increased through genetically improved plant materials and better and more intensive management systems.

Breeding efforts in orchardgrass and forage-type perennial ryegrass have historically been concentrated on forage traits (yield and quality), disease resistance, and adaptation to the more humid, temperate regions of the world (Balasko et al., 1995; Casler et al., 1997; Christie and McElroy, 1995; Jung et al., 1996; Stratton and Ohm, 1989). With the exception of the dryland orchardgrass cultivar Paiute, which originated from a single plant introduction (PI-109072) (Alderson and Sharp, 1994), very little breeding has been done to develop improved cultivars of cool-season perennial grasses for irrigated pastures in the Intermountain West. Plant growth in this environment is frequently limited by lack of soil water during the later portions of the growing season. Ideally, improved cultivars must have adaptations that allow them to maintain forage production under water-limiting conditions.

Plant selections under dryland conditions (Asay and Johnson, 1983) have resulted in improved forage production and quality within the crested wheatgrasses (*Agropyron* spp.) (Asay et al., 1985a; Asay et al., 1995; Asay et al., 1997; and Asay et al., 1999) and Russian wildryes [*Psathyrostachys juncea* (Fisch.) Nevski (Asay et al., 1985b; Jensen et al., 1998] on marginally productive semiarid rangelands. Johnson and Bassett (1991) reported significant differences in water use efficiency (dry matter produced per unit of water consumed) between accessions of perennial ryegrass, orchardgrass, and tall fescue when grown under dryland and irrigated conditions. With the ever-increasing demands for water in the Intermountain West, there is a critical need to develop improved cool-season forage pasture grasses that maintain productivity under periods of limited irrigation.

Orchardgrass is a native of Europe but has been grown for over 200 yr in North America, where it occupies an important place as a cultivated grass for hay and pasture. A breeding history of orchardgrass was reviewed by Casler et al. (2000). It is one of the major grass species for pastures in areas of high rainfall in the Northeast, North Central, and Pacific Northwest regions of the USA (Hoveland, 1992). It has been used west of the Rocky Mountains where adequate irrigation is available. Its major limitation in the Great Basin is its need for high soil water supply throughout the growing season.

Perennial ryegrass is a temperate perennial grass that is indigenous to southern Europe, North Africa, and southwest Asia. Because of its high forage quality, it is one of the most important pasture grasses throughout western Europe, New Zealand, and the northwestern USA. It has become an important pasture species in eastern Canada and southern British Columbia (Smoliak, 1992; Balasko et al., 1995). Within the Great Basin, perennial ryegrass does not persist in highly productive stands for more than a few years unless it is reseeded to thicken declining stands. However, despite its short-lived nature, the reputation of perennial ryegrass generates interest for intensively managed pastures on dairy operations (Jensen, 1995).

K.B. Jensen, K.H. Asay, and B.L. Waldron, USDA-ARS, Forage and Range Research Laboratory, Utah State Univ., Logan, UT 84322-6300. Cooperative investigations of the USDA-ARS and the Utah Agric. Exp. Stn., Logan Utah 84322. Approved Journal Paper No. 7227. Received 1 Dec. 1999. *Corresponding author (kevin@cc.usu.edu).

Published in Crop Sci. 41:479–487 (2001).

Abbreviations: DM, dry matter; WL, water level(s); RS, *Elytrigia repens* (L.) Nevski × *Pseudoroegneria spicata* (Pursh) A. Love.

Table 1. Mean squares (based on type III sums of squares, non-additive) from analysis of variance for dry matter production of nine cultivars of orchardgrass and nine perennial ryegrass/hybrids, and check cultivars of meadow and smooth bromegrass, tall fescue, and RS-wheatgrass hybrid at five water levels in 1997–1998. Mean squares for replications and interactions with replications not shown.

Source of variation	df	Year		
		1997	1998	1997–1998
			Mg ha^{-1}	
Cultivars (C)	21	305.01**	324.13**	604.38**
Species (Sp)	5	1180.4**	1178.81**	2302.02**
C(Sp)	16	31.45**	57.05**	73.87**
Orchardgrass (OG)	8	26.44*	40.6**	60.37**
Perennial Ryegrass (PRG)	8	36.46**	73.5**	87.37**
Water levels (WL)	4	1100.96 nv†	233.39 nv	1143.36 nv
C × WL	84	4.56**	6.48**	9.01**
Sp × WL	20	13.5**	21.29**	30.14**
C(Sp) × WL	64	1.77*	1.85**	2.41**
OG × WL	32	1.7 ns	2.43**	2.93*
PRG × WL	32	1.84*	1.27*	1.89*
Years (Y)	1			2857.3**
C × Y	21			24.76**
Sp × Y	5			57.18**
C(Sp) × Y	16			14.63**
OG × Y	8			6.66*
PRG × Y	8			22.59**
C × WL × Y	84			2.03**
Sp × WL × Y	20			4.65**
C(Sp) × WL × Y	64			1.21*
OG × WL × Y	32			1.2 ns
PRG × WL × Y	32			1.22**

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
ns = not significant.
† nv = no valid *F*-test for water levels.

A line-source irrigation system has been employed to evaluate forage yield and seasonal forage distribution of orchardgrass and perennial ryegrass cultivars along with check cultivars of smooth and meadow brome, tall fescue, and RS-hybrid wheatgrass. Johnson et al. (1982) and Rumbaugh et al. (1984) concluded that the line-source design would have merit in a forage breeding program for evaluating genetic responses to water stress. The line-source sprinkler plot irrigation system produces a nearly linear (Hanks et al., 1980) water application pattern with the amount of irrigation declining as a function of distance from the sprinkler line. The major limitation with the line-source sprinkler system is that water levels (WL) are not imposed randomly for each plot. Consequently, a valid error term is not available in the analysis of variance for testing the main effect of WL (Hanks et al., 1980). However, the tests for genotype × WL interactions are valid, providing that the

Table 2. Mean dry matter production grown under five irrigation levels averaged across 1997–1998 and proportion of water level sum of squares due to linear, quadratic, and cubic trends of six pasture species.

Species	No. of cultivars	Water levels					Mean	Orthogonal trends†		
		1	2	3	4	5		Linear	Quadratic	Cubic
		Mg ha^{-1}								
Orchardgrass	9	19.3	18.9	17.6	15.6	10.5	16.4	83.0**	16.1**	0.3 ns
Perennial Ryegrass (PRG)	9	11.1	10.8	10.2	8.8	6.4	9.5	86.1**	13.1**	0.1 ns
PRG-2*x* vs PRG-4*x*‡		ns§	ns	**	**	**	**			
Checks:										
Tall Fescue	1	22.5	22.3	22.2	20.8	16.6	20.9	66.4**	29.7**	3.8 ns
Meadow Brome	1	16.1	16.4	17.0	16.2	14.0	16.0	33.7**	60.2**	3.6 ns
Smooth Brome	1	12.3	11.8	13.4	10.9	9.0	11.5	40.9**	33.1**	3.2 ns
RS Hybrid	1	11.1	13.3	12.7	11.4	9.4	11.9	72.5**	26.0**	0.5 ns
Contrasts:‡										
Orchardgrass vs Perennial Ryegrass		**	**	**	**	**	**			
Orchardgrass vs Tall Fescue		**	**	**	**	**	**			
Orchardgrass vs Meadow Brome		**	**	ns	ns	**	ns			
Orchardgrass vs Smooth Brome		**	**	**	**	*	**			
Orchardgrass vs RS Hybrid		**	**	**	**	ns	**			
Orchardgrass vs RS Hybrid		**	**	**	**	ns	**			
Perennial Ryegrass vs Tall Fescue		**	**	**	**	**	**			
Perennial Ryegrass vs Meadow Brome		**	**	**	**	**	**			
Perennial Ryegrass vs Smooth Brome		ns	ns	**	*	**	**			
Perennial Ryegrass vs RS Hybrid		ns	**	*	**	**	**			

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
ns = not significant.
† Percent of WL sums of squares due to linear, quadratic, and cubic trends, based on orthogonal polynomials.
‡ Based on single degree of freedom contrasts.

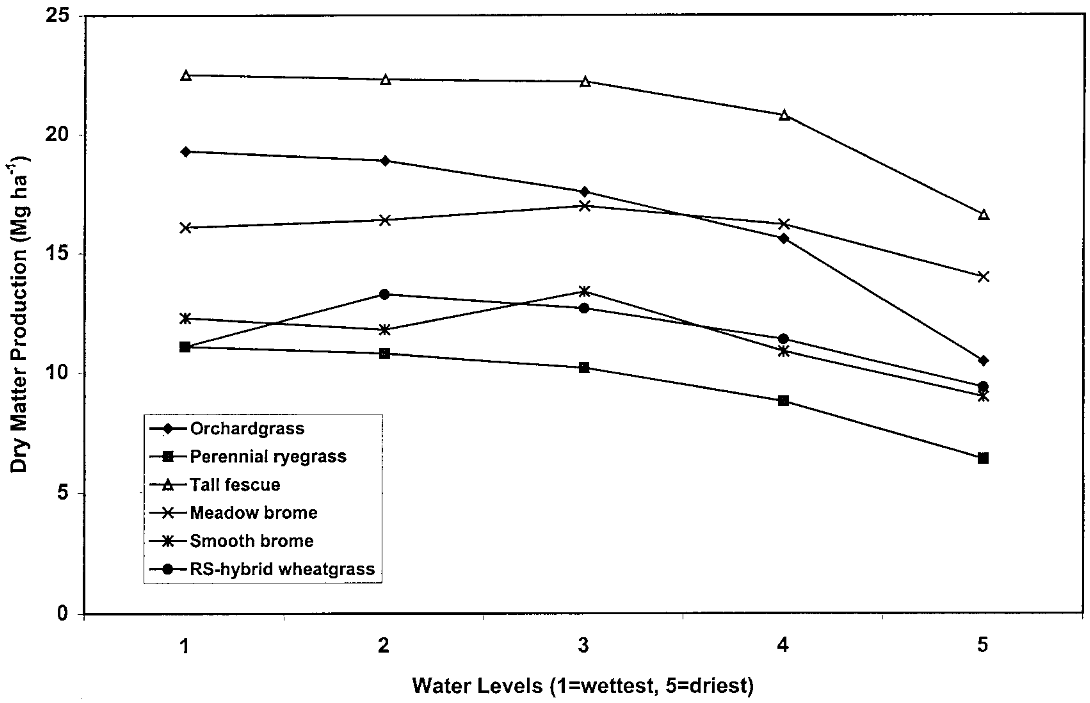

Fig. 1. Total dry matter production within water levels combined over years and across harvests for six irrigated pasture grasses.

genotype treatments are randomized. Objectives in this experiment were to (i) study responses of individual species and cultivars to different levels of irrigation and genotype by WL interactions; and (ii) determine effects of irrigation level on seasonal distribution of forage yield.

MATERIALS AND METHODS

Nine orchardgrass, nine perennial ryegrass-hybrids, and four check cultivars were included in the line-source trials. The orchardgrass cultivars were: Ambassador, Dawn, DS-8, Justus, Latar (late maturing), Paiute (dryland), Pizza, Potomac, and Sampson. The perennial ryegrass cultivars, all endophyte free, included Citadel (4*x*), Bastion (4*x*), Zero Nui (2*x*), Cambridge (2*x*), Moy (2*x*), Barmaco (2*x*), Gambit (4*x*), Bison (4*x*) (annual ryegrass [*L. multiflorum* Lam.) × perennial ryegrass], and Tandem (4*x*) (annual ryegrass × meadow fescue (F. pratensis Huds.) hybrid). The check cultivars included Manchar smooth brome, Regar meadow brome, Fawn tall fescue (E$^-$), and RS-hybrid (Jensen and Asay, 1996).

Seed of Pizza orchardgrass, Citadel, Bastion ryegrasses, and Tandem ryegrass fescue hybrid were provided by Advanta Seeds Pacific Inc.[1], Albany, OR. International Seeds Inc., Halsey, OR, supplied Ambassador, Justus, and Sampson orchardgrass, and Cambridge, Gambit, and Bison perennial ryegrasses and hybrid, respectively. Seed lots of Zero Nui, Moy, and Barmaco perennial ryegrass were supplied by Barenbrug USA, Tangent, OR. The orchardgrass breeding line DS-8 and cultivar Dawn were obtained from Land O' Lakes Research, Webster City, IA. All other cultivars were developed by public institutions as described in Alderson and Sharp (1994).

The experiment was located at the Utah State University Evans Experimental Farm, approximately 2 km south of Logan, UT, (41° 45′ N, 111° 8′ W, 1350 m above sea level). Soil at the site was a Nibley silty clay loam (fine, mixed, mesic Aquic Argiustolls). Ten year (1990–1999) annual precipitation at the site was 475 mm with about one-half occurring May through October. Total precipitation (excluding irrigation) received from October through September was 584 and 748 mm for 1997 and 1998, respectively. Mean minimum and maximum monthly temperatures in 1997 were 5.6 and 21.8°C for May, 8.7 and 25.4°C for June, 10.8 and 28.7°C for July, 11.4 and 29.7°C for August, 8.4 and 24.5°C for September, and −1.1 and 16.7°C for October. Corresponding values for 1998 were 4.8 and 19.2°C for May, 6.8 and 21.3°C for June, 12.9 and 32.7°C for July, 11.4 and 29.7°C for August, 8.7 and 24.5°C for September, and 0.0 and 16.7°C for October. Sward plots (16 by 1 m) were planted early May 1995 with a 6-row Wintersteiger cone seeder (Wintersteiger Corporation, Salt Lake City, UT) at a depth of 1.3 cm. The seeding rate for each cultivar was approximately 135 seeds per linear meter of row. Rows were spaced 15 cm apart. Plots were oriented perpendicular to a line-source irrigation system and divided into five WLs on each side of the irrigation line. Each WL plot was 2.0 m^2 (2 by 1 m), and spaced at 2-m intervals from the line-source sprinkler. The plots were arranged in a modified spilt-plot design with the 22 cultivars as whole plots and the five WLs as subplots. The design was replicated four times, twice on each side of the line-source irrigation line.

During the establishment year (1995), plots were irrigated uniformly as needed and received 56 kg N ha^{-1} in mid-summer and again in early October. Previous soil tests suggested that P and K were sufficient throughout the farm. Irrigation water plus rainfall was monitored from April through October in 1996, 1997, and 1998. Amounts of irrigation water plus rain applied to WL 5 through 1, respectively, were 15, 36, 43, 57, and 67 cm in 1996; 40, 55, 63, 78, and 93 cm in 1997; and 42, 55, 63, 77, and 89 cm in 1998. Supplemental irrigation was applied weekly to ensure that WL-1 received 5 cm per week. Because a soil water gradient was not fully established in 1996, only results from 1997 and 1998 were considered in this report. Fertilizer applications, each 56 kg N ha^{-1}, were made before Harvest 1 and after Harvests 2, 4, and 6 in 1996 and 1997.

[1] Mention of any trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply approval or the exclusion of other products that may also be suitable.

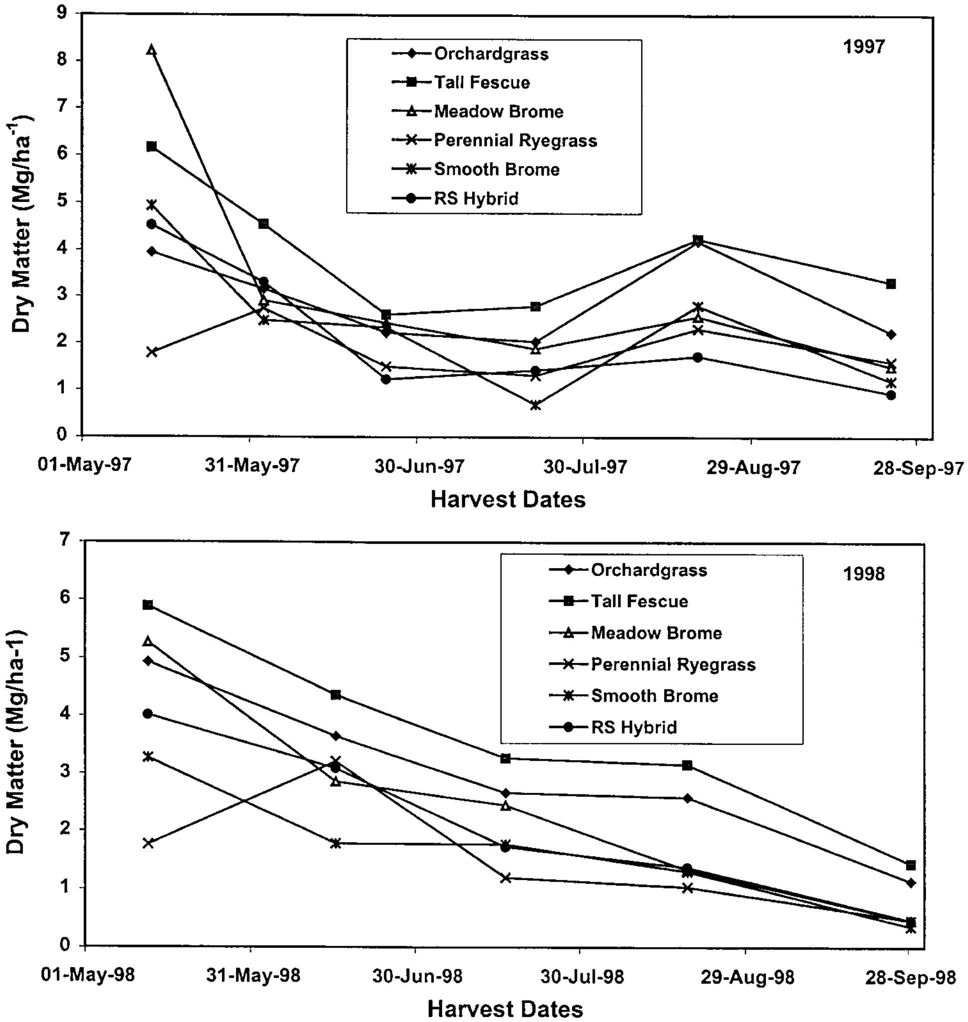

Fig. 2. Trends in dry matter production of six pasture grasses combined across five water levels for six harvest dates in 1997 (upper) and five harvest dates in 1998 (lower).

Only five harvests were taken in 1998 because of a very wet spring, thus fertilizer treatments were applied before Harvest 1 and after Harvests 2, 4, and 5.

Plots were harvested to an 8-cm stubble height by a Swift Current sickle bar harvester (Swift Machining & Welding LTD, Swift Current, SK, Canada) when the majority of the species were in the boot stage of development at the first harvest. Subsequent harvests occurred when the majority of the species regrowth reached 25 to 30 cm in height from 12 May through 1 October. It is recognized that some of the later maturing cultivars may not have been harvested at their optimum, particularly at the first harvest. Harvest dates were 13 May, 2 and 24 June, 21 July, 19 August, and 23 September in 1997 and 12 May, 15 June, 16 July, 18 August, and 28 September in 1998. Forage samples used to estimate dry matter (DM) production were dried at 60°C in a forced-air oven to constant weight. Dry matter production was analyzed as a split-plot within years. *F*-tests of main effects and interactions were made considering years, cultivars, and levels as fixed. All data were subjected to analysis of variance by GLM procedures with type III sums of squares, which are nonadditive. Mean separations were made on the basis of least significant differences (LSD) at the 0.05 probability level (SAS Institute Inc., 1994). Linear, quadratic, and cubic trends of water levels were evaluated by orthogonal polynomials with uneven spacings (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Species

Dry matter production ranged from 26.9 Mg ha^{-1} in tall fescue to 6.1 Mg ha^{-1} in perennial ryegrass across WLs in 1997 and from 19.1 Mg ha^{-1} in tall fescue to 6.7 Mg ha^{-1} in perennial ryegrass in 1998. Mean DM production rankings across WLs combined over years were tall fescue > orchardgrass > meadow brome > RS-hybrid wheatgrass > smooth brome > perennial ryegrass. Relative differences among species for DM production were not consistent across WLs as evidenced by a significant ($P < 0.01$) species by WL interaction for each year and in the analysis combined over years (Table 1). Within each year, the relative differences were due to an increase in DM production and rank change in the different species at lower WLs. Increased DM production at lower WLs was more pronounced in 1998 becaue of a possible build-up of nitrogen resulting from reduced leaching at lower WLs. In addition, a decline in DM production of later maturing species, particularly perennial ryegrass in 1998, influenced the species rank change between years. During the 1997-1998 winter, perennial ryegrass experienced severe win-

Table 3. Mean dry matter production within nine cultivars of orchardgrass and nine perennial ryegrass/hybrid cultivars grown under five irrigation levels during 1997–1998 and their proportion of water level sum of squares due to linear, quadratic, and cubic trends.

	Water levels						Orthogonal trends†		
Species and cultivars	1	2	3	4	5	Mean	Linear	Quadratic	Cubic
	Mg ha^{-1} dry matter								
Orchardgrass									
Ambassador	20.2	19.3	18.3	16.3	12.2	17.2	87.4**	11.6**	0.5 ns
Dawn	20.7	20.2	19.2	16.5	10.4	17.4	80.6**	18.4**	0.6 ns
DS-8	19.6	18.8	17.1	14.8	9.1	15.9	86.7**	12.9**	0.3 ns
Justus	18.4	18.4	17.0	14.4	9.5	15.5	82.1**	17.6**	0.1 ns
Latar (late maturing)	19.5	18.6	17.2	15.7	9.7	16.1	83.4**	15.2**	1.3 ns
Paiute (dryland)	19.7	19.0	19.0	18.0	12.7	17.7	65.0**	28.7**	6.0*
Pizza	17.8	18.5	16.3	14.6	9.9	15.4	81.2**	18.2**	0.2 ns
Potomac	20.7	20.5	18.9	16.9	12.3	17.9	85.5**	14.3**	0.0 ns
Sampson	17.4	16.6	15.1	13.4	8.9	14.3	88.9**	10.8**	0.2 ns
LSD (0.05)	2.4	1.8	1.9	1.8	1.7	1.5			
Perennial ryegrass									
Bison-4*x*‡	14.6	13.8	13.0	11.2	9.2	12.3	92.3**	5.7*	0.0 ns
Tandem-4*x*§	12.9	13.1	11.8	9.9	6.7	10.8	84.0**	15.4**	0.2 ns
Citadel-4*x*	12.1	11.7	10.9	9.3	6.6	10.1	87.7**	11.8*	0.1 ns
Bastion-4*x*	11.2	10.7	10.0	9.1	6.9	9.6	89.1**	11.3*	0.5 ns
Gambit-4*x*	10.1	9.7	9.8	7.7	5.7	8.6	78.6**	15.5*	0.1 ns
Zero Nui-2*x*	10.2	9.6	8.6	7.4	5.9	8.3	97.3**	2.5 ns	0.1 ns
Cambridge-2*x*	10.0	10.9	9.3	8.8	6.2	9.0	73.7**	23.7*	0.9 ns
Moy-2*x*	10.1	9.9	9.7	8.5	6.1	8.9	79.7**	18.1**	1.4 ns
Barmaco-2*x*	9.1	8.0	8.7	7.1	4.1	7.4	72.0**	17.9**	6.1**
LSD (0.05)	2.1	1.7	1.7	1.5	1.5	1.4			

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
ns = not significant.
† Percent of WL sums of squares due to linear, quadratic, and cubic trends, based on orthogonal Polynomials.
‡ Annual ryegrass/perennial ryegrass hybrid.
§ Annual ryegrass/meadow fescue hybrid.

ter injury and had not recovered by the May 1998 harvest.

Combined over years and within years, the decline in DM production with decreasing water applied was mostly linear ($P < 0.01$) with a quadratic component ($P < 0.05$) in tall fescue, orchardgrass, perennial ryegrass, and RS-hybrid wheatgrass (Table 2). Although the linear effect was significant ($P < 0.01$) in meadow brome, most of the decline in DM production was quadratic (Table 2), in part because of an increase in DM production from 16.4 to 17.0 Mg ha^{-1} from WL-2 to WL-3. The response curve of DM production to decreased water in smooth bromegrass was linear ($P < 0.01$), with the exception of a sharp increase in DM production from 11.8 to 13.4 Mg ha^{-1} from WL-2 to WL-3.

Tall fescue was the most responsive to increased WLs (Table 2). Orchardgrass and meadow brome were not significantly different in DM production when averaged across WLs (Table 2). Under WL 5 and 4, meadow brome produced more DM than orchardgrass, while orchardgrass was more responsive to increasing WLs (Fig. 1). Despite the reduced total DM production in smooth brome and RS-hybrid wheatgrass, forage production was relatively stable across WLs (Table 2). Dry matter production in perennial ryegrass was the lowest at lower WLs, but was responsive to increased WLs (Fig. 1) (Table 2).

Seasonal trends in DM production of species across harvests varied according to year. In 1998, there was an overall decline in DM production across species. During 1997 and 1998, rapid spring growth was evident in all species except perennial ryegrass, which had reduced DM production during Harvest 1 (Fig. 2). However, perennial ryegrass had an increase in DM production at Harvest 2 (Table 2). After rapid spring growth, DM production in general declined until the August harvests where at the higher water rates DM production remained constant or increased, particularly for tall fescue, smooth brome, and orchardgrass.

Orchardgrass Cultivars

Significant differences in DM production were found among orchardgrass cultivars within each WL (Table 3). Dry matter production ranged from 21.2 Mg ha^{-1} for Dawn and Potomac to 8.9 Mg ha^{-1} for Sampson across WLs in 1997 and from 19.7 Mg ha^{-1} for Potomac to 8.9 Mg ha^{-1} for Sampson in 1998. Relative differences among orchardgrass cultivars for DM production were consistent across WLs in 1997 as evidenced by a nonsignificant orchardgrass by WL interaction (Table 1). However, that interaction was significant ($P < 0.01$) in 1998 due to a much lower decline in DM production and a rank change in Paiute between WLs 5 and 4 (Table 3). The dryland cultivar Paiute outyielded ($P < 0.05$) the combined means of the irrigated orchardgrass cultivars at the lower two WLs (Fig. 3). Within WLs, there was no difference in DM production between early and late maturing orchardgrass cultivars. When averaged over years, WLs, and harvests, orchardgrass cultivars Ambassador, Potomac, Paiute, and Dawn were not significantly different in DM production (Table 3).

The sum of squares due to linear trends in DM production across WLs was significant ($P < 0.01$) for each year and in the analysis combined over years (Table 3) for all orchardgrass cultivars. Quadratic trends for DM production were significant ($P < 0.05$) in 1997 and 1998,

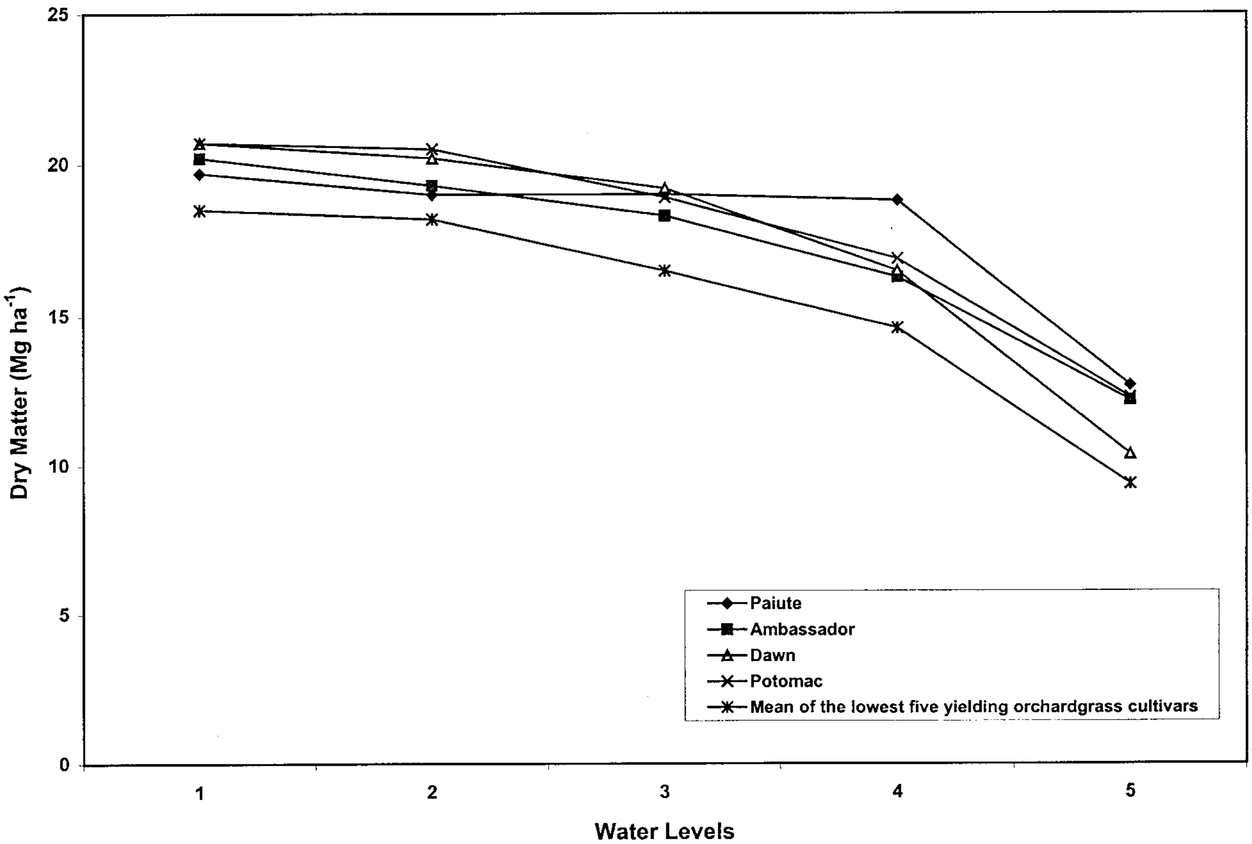

Fig. 3. Trends in dry matter production of Paiute (dryland) orchardgrass and three top yielding irrigated orchardgrass cultivars and the mean of the five lowest yielding orchardgrass cultivars combined over years and across harvests.

except for cultivars Potomac and Sampson, which were essentially linear in their response in 1998.

Paiute was least affected of the orchardgrass cultivars by the changing WLs (Fig. 3; Table 3). Combined over years, Latar, which is a later maturing cultivar, yielded more DM ($P > 0.05$) at Harvest 2; however, cultivars Ambassador, Potomac, Paiute, and Dawn produced more ($P < 0.05$) total DM than Latar across all harvests (Table 4). Seasonal trends within orchardgrass cultivars exhibited early spring growth followed by a decline in DM production. An increase in DM yield was observed at the August harvests followed by a DM reduction in early fall (Fig. 4). During Harvest 1 in both years, DM production was higher than expected at lower WLs (Fig. 4). Presumably this increase in DM production was due to a build-up of nitrogen because of reduced leaching in the soil profile at lower WLs.

Perennial Ryegrass and Hybrids

Mean DM production of the nine perennial ryegrass-hybrid cultivars was significantly lower ($P < 0.01$) than all orchardgrass cultivars and species evaluated at a given harvest across WLs and in most cases within WLs (Table 2). Differences among perennial ryegrass-hybrid cultivars for DM production were significant ($P < 0.05$) in the combined analysis at all five WLs (Table 3). Hybrid cultivars Bison (annual ryegrass × perennial ryegrass) and Tandem (annual ryegrass × meadow fescue) outyielded all perennial ryegrass cultivars at all WLs (Table 3). Mean DM production ranged from 15.9 Mg ha^{-1} for Bison to 3.7 Mg ha^{-1} for Barmaco across WLs in 1997, and from 13.2 Mg ha^{-1} for Bison to 4.4 Mg ha^{-1} for Barmaco in 1998. With the exception of WL-5, Citadel and Bastion were the highest yielding perennial ryegrasses combined over years (Table 3). Combined over years, tetraploid ($2n = 28$) perennial ryegrasses produced more DM at all WLs than did the diploids. However, only at WLs 3 and 5 were ploidy levels different significantly ($P < 0.05$) (Fig. 5; Table 2).

Comparative differences among perennial ryegrass-hybrid cultivars for DM production were not consistent across WLs, as indicated by the significant ($P < 0.05$) cultivar by WL interaction across years (Table 1). This interaction was due to an overall decline in DM production in 1998 and a rank change in Zero Nui from WL-4 to WL-5 in 1998.

With the exception of Zeo Nui, which was only linear in its response to increased WLs, linear and quadratic trends were significant in the combined analysis (Table 3). The quadratic response in perennial ryegrass resulted from a relatively stable forage yield across WLs 1, 2, and 3 followed by a decline at WLs 4 and 5 (Fig. 1).

Responsiveness of perennial ryegrass-hybrid entries to changing WLs varied. Intermediate ryegrass cultivar Bison and perennial ryegrass cultivar Zero Nui were the most stable across WLs (Table 3). Even though the annual-perennial ryegrass hybrid Bison was the least responsive as WLs increased, it had the highest DM production of all entries within each WL (Table 3).

Table 4. Mean dry matter production within nine cultivars of orchardgrass and nine perennial ryegrass/hybrid cultivars harvested from May through September during 1997 and 1998 combined over WLs.

	Harvests 1997						Harvests 1998				
Species and cultivars	1	2	3	4	5	6	1	2	3	4	5
	Mg ha^{-1} dry matter										
Orchardgrass											
Ambassador	4.3	2.4	2.4	2.3	4.5	2.5	6.6	2.8	2.7	2.7	1.3
Dawn	4.1	3.5	2.4	2.1	4.3	2.5	5.2	3.8	2.8	2.6	1.2
DS-8	3.3	4.2	1.9	1.9	4.1	2.1	3.3	4.8	2.5	2.6	1.2
Justus	3.8	2.5	2.0	2.0	4.3	2.3	5.2	2.8	2.4	2.4	1.3
Latar (late maturing)	3.3	3.7	2.6	2.0	4.1	2.2	3.4	4.8	2.7	2.6	0.9
Paiute (dryland)	4.9	2.7	2.4	2.2	4.2	2.3	6.4	3.2	3.2	2.8	1.1
Pizza	4.1	3.3	2.2	2.0	4.1	2.0	3.7	3.6	2.6	2.3	1.0
Potomac	4.9	2.9	2.2	2.0	4.5	2.4	6.9	3.4	2.7	2.7	1.2
Sampson	2.9	3.1	1.9	1.9	3.7	1.8	3.7	3.6	2.5	2.4	1.1
LSD (0.05)	0.85	0.64	0.41	0.37	0.41	0.36	0.74	0.55	0.35	0.28	0.22
Perennial ryegrass											
Bison-4*x*†	1.3	3.0	1.9	2.1	2.7	1.9	3.6	3.9	1.9	1.5	0.9
Tandem-4*x*‡	2.0	3.1	1.3	1.6	2.4	1.9	2.8	3.0	1.5	1.5	0.6
Citadel-4*x*	2.6	3.0	1.6	1.4	2.5	1.6	1.3	3.7	1.0	1.0	0.5
Bastion-4*x*	2.7	2.8	1.5	1.1	2.1	1.6	2.0	3.2	0.9	0.8	0.5
Gambit-4*x*	2.7	2.5	1.2	0.9	2.0	1.4	2.0	2.5	0.9	0.8	0.3
Zero Nui-2*x*	0.7	2.1	1.3	1.3	2.2	1.4	1.6	3.0	1.3	1.1	0.5
Cambridge-2*x*	1.5	3.1	1.7	1.1	2.4	1.5	0.8	4.0	0.8	0.9	0.3
Moy-2*x*	2.1	2.7	1.3	1.1	2.3	1.6	1.5	3.1	1.0	0.8	0.3
Barmaco-2*x*	0.5	2.3	1.6	1.3	2.3	1.5	0.3	2.4	1.3	1.0	0.3
LSD (0.05)	0.87	0.69	0.48	0.26	0.63	0.46	0.67	0.73	0.24	0.31	0.15

† Annual ryegrass/perennial ryegrass hybrid.
‡ Annual ryegrass/meadow fescue hybrid.

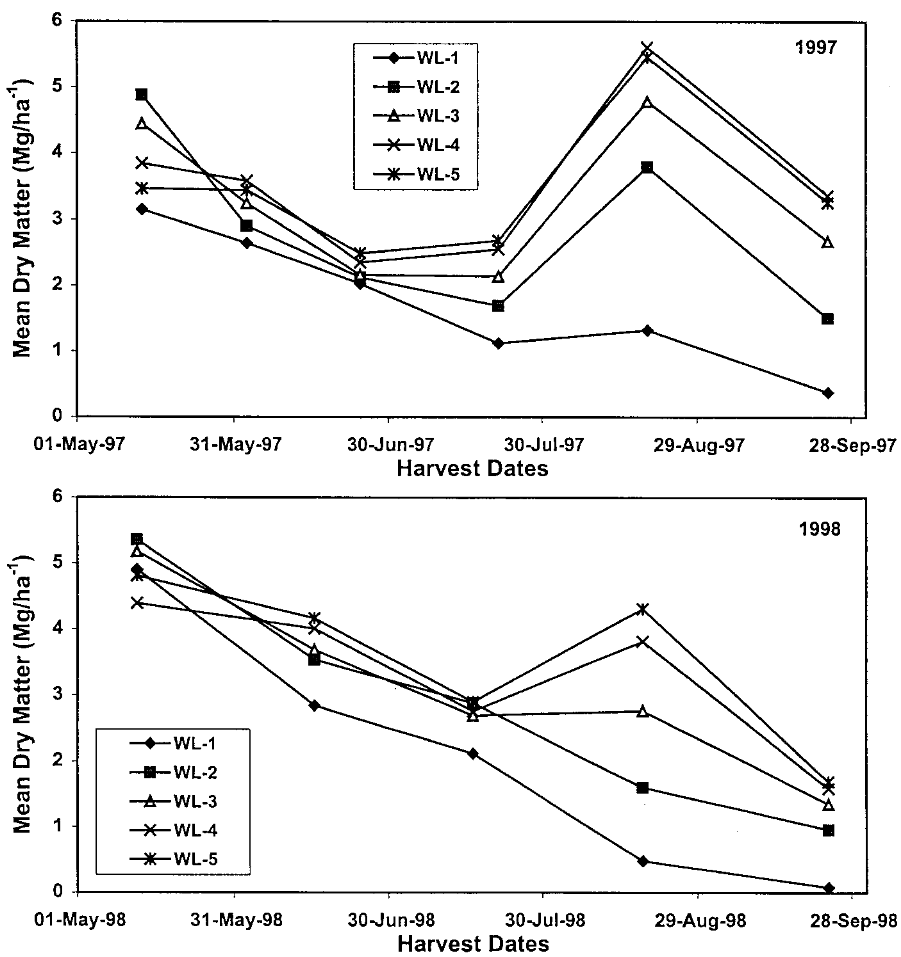

Fig. 4. Trends in dry matter production of nine orchardgrass cultivars across six harvest dates in 1997 (upper) and five harvest dates in 1998 (lower).

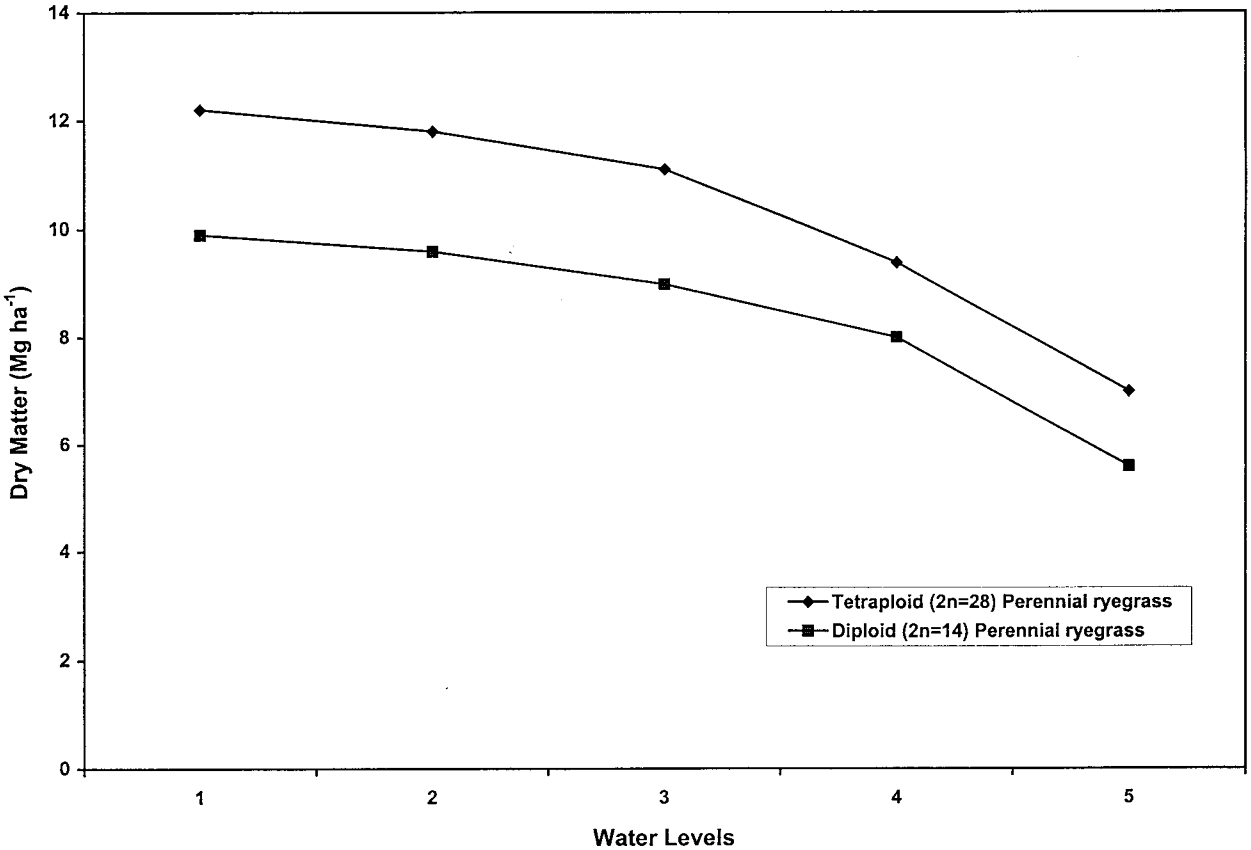

Fig. 5. Trends in dry matter production of tetraploid ($2n = 28$) and diploid ($2n = 14$) perennial ryegrass cultivars across five water levels with all harvests.

Citadel was the highest yielding and most responsive perennial ryegrass to increased WLs (Table 3).

Mean DM production varied significantly ($P < 0.05$) within harvests for the different perennial ryegrass cultivars (Table 4). In both 1997 and 1998, the perennial ryegrass-hybrid cultivars lacked the initial rapid spring growth exhibited by the other cool-season grasses at Harvest 1 with a subsequent increase at Harvest 2 (Fig. 2). Tetraploid perennial ryegrass cultivars outyielded ($P < 0.01$) the diploids in Harvest 1 (Fig. 6). However, in subsequent harvests, DM production was similar in both ploidy levels. Severe winter injury, particularly in the diploids, contributed to the reduced DM production at Harvest 1 combined over years.

CONCLUSIONS

In the development of improved pastures, the choice of species and cultivars along with an understanding of water requirements is critical in providing a stable source of forage throughout the grazing season. This is particularly so in the Intermountain Region, where irrigation frequently becomes limited during the latter part of the season. Tall fescue produced more DM at all WLs than other species. Under limited irrigation, meadow brome outyielded orchardgrass. However, when water was not limited, orchardgrass outyielded meadow brome. RS-hybrid wheatgrass and smooth bromegrass were less responsive to increased WLs than the other species (Table 2). All species produced significantly more DM than perennial ryegrass at lower rates of irrigation.

Except for Paiute, relative ranking among orchardgrass cultivars appeared fairly consistent at each WL (Table 3). The variation within orchardgrass cultivars for DM production was the highest at the lower two WLs, suggesting that plant selection for improved DM production in orchardgrass may be more effective under limited irrigation rather than at optimum irrigation levels. Of the ryegrasses and hybrids, intermediate ryegrass (cv. Bison) shows the most promise as an irrigated pasture grass; however, additional studies to determine long-term persistence in the Intermountain Region are needed.

REFERENCES

Alderson, J., and W.C. Sharp. 1994. Grass varieties in the United States. USDA Agric. Handbook No. 170. U.S. Gov. Print. Office, Washington, DC.

Asay, K.H., N.J. Chatterton, K.B. Jensen, R. R-C. Wang, D.A. Johnson, and W.H. Horton. 1997. Registration of 'CD-II' crested wheatgrass. Crop Sci. 37:1023.

Asay, K.H., D.R. Dewey, F.B. Gomm, D.A. Johnson., and J.R. Carlson. 1985a. Registration of 'Hycrest' crested wheatgrass. Crop Sci. 25:368–369.

Asay, K.H., D.R. Dewey, F.B. Gomm, D.A. Johnson., and J.R. Carlson. 1985b. Registration of 'Bozoisky-Select' Russian wildrye. Crop Sci. 25:575–576.

Asay, K.H., K.B. Jensen, W.H. Horton, D.A. Johnson, N.J. Chatterton, and S.A. Young. 1999. Registration of 'RoadCrest' crested wheatgrass. Crop Sci. 39:1535.

Asay, K.H., and D.A. Johnson. 1983. Breeding for drought resistance in range grasses. Iowa State J. Res. 57:441–455.

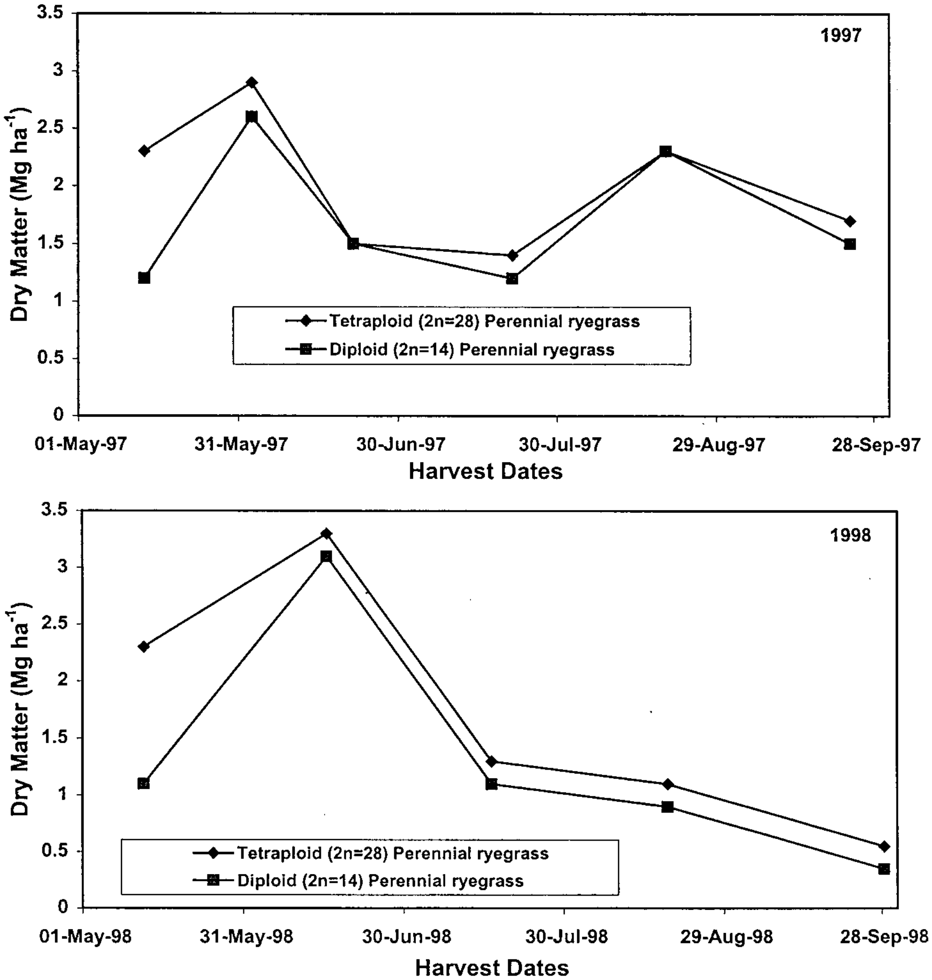

Fig. 6. Trends in dry matter production of tetraploid ($2n = 28$) and diploid ($2n = 14$) perennial ryegrass cultivars combined across five water levels for six harvest dates in 1997 (upper) and five harvest dates in 1998 (lower).

Asay, K.H., D.A. Johnson, K.B. Jensen, N.J. Chatterton, W.H. Horton, W.T. Hansen, and S.A. Young. 1995. Registration of 'Vavilov' Siberian crested wheatgrass. Crop Sci. 35:1510.

Balasko, J.A., G.W. Evers, and R.W. Duell. 1995. Bluegrasses, ryegrasses, and bentgrasses. p. 357–368, *In* R.F Barnes et al. (ed.) Forages, Volume 1: An introduction to grassland agriculture. Iowa State University Press, Ames, IA.

Bateman, G.Q., and W. Keller. 1956. Grass-legume mixtures on irrigated pastures for dairy cattle. Utah State Agric. Exp. Stn. Bull. 382.

Casler, M.D., C.C. Berg, I.T. Carlson, and D.A. Sleper. 1997. Convergent-divergent selection for seed production and forage traits in orchardgrass. II. Correlated responses for forage traits. Crop Sci. 37:1059–1065.

Casler, M.D., S.L. Fales, A.R. McElroy, M.H. Hall, L.D. Hoffman, and K.T. Leath. 2000. Genetic progress from 40 years of orchardgrass breeding in North America measured under hay management. Crop Sci. 40:1019–1024.

Christie, B.R., and A.R. McElroy. 1995. Orchardgrass. p. 325–334. *In* R.F Barnes et al. (ed.) Forages, Volume 1: An introduction to grassland agriculture. Iowa State University Press, Ames, IA.

Gomez, K.A., and A.A. Gomez. 1984. Statistical procedures for agricultural research. 2nd ed. John Wiley & Sons, New York.

Hanks, R.J., D.V. Sisson, R.L. Hurst, and K.G. Hubbard. 1980. Statistical analysis of results from irrigation experiments using the line source sprinkler system. Soil Sci. Soc. Am. J. 44:886–888.

Hoveland, C.S. 1992. Grazing systems for humid regions. J. Prod. Agric. 5:23–27.

Jensen, K.B. 1995. Forage materials. *In* D.L. Coppock et al. (Compilers). 1995. Utah pasture grazing lands research and development: technical white paper. Unpublished Report. Utah Agri. Exp. Stn. Utah State Univ. Logan, UT.

Jensen, K.B., and K.H. Asay. 1996. Cytology and morphology of *Elymus hoffmannii* (Poaceae: Triticeae): A new species from the Erzurum Province of Turkey. Int. J. Plant Sci. 157:750–758.

Jensen, K.B., K.H. Asay, D.A. Johnson, W.H. Horton, A.J. Palazzo, and N.J. Chatterton. 1998. Registration of tetraploid Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski] RWR-Tetra-1 germplasm. Crop Sci. 38:1405.

Johnson, D.A., L.S. Willardson, K.H. Asay, D.N. Rinehart, and M.R. Aurasteh. 1982. A greenhouse line-source sprinkler system for evaluating plant response to a water application gradient. Crop Sci. 22:441–444.

Johnson, R.C., and L.M. Bassett. 1991. Carbon isotope discrimination and water use efficiency in four cool-season grasses. Crop Sci. 31:157–162.

Jung, G.A., A.J.P. Van Wijk, W.F. Hunt, and C.E. Watson. 1996. Ryegrasses. p. 605–641. *In* L.E. Moser et al. (ed.) Cool-season forage grasses. Agron. Monog. 34. ASA, CSSA, and SSSA, Madison, WI.

Rumbaugh, M.D., K.H. Asay, and D.A. Johnson. 1984. Influence of drought stress on genetic variances of alfalfa and wheatgrass seedlings. Crop Sci. 24:297–303.

SAS Institute Inc. 1994. SAS/STAT users guide, ver. 6, 4th ed. Cary, NC.

Smoliak, S. 1992. Hay and pasture crops. p. 7–37. *In* Alberta forage manual. Fourth ed. Alberta Forage Crops Advisory Committee. Media Branch, Alberta Agriculture, Edmonton, AB, Canada.

Stratton, S.D., and H.W. Ohm. 1989. Relationship between orchardgrass seed production in Indiana and Oregon. Crop Sci. 29:908–913.